CLAIMS

WHAT IS CLAIMED IS:

1. An apparatus for stabilizing the spin axis of a rotating system, said rotating system comprising:

a rotor carrying and inertial load and bearing means to support said rotor about said spin axis, and

motor means to cause rotation of said rotor about said spin axis comprising:

a first set of windings;

a source of drive current for causing relative rotation between said windings and said magnet; and

an actuator combined with a motor and comprising a source of actuator current energizing said windings to generate a radial force which stabilizes the position of said spin axis and dampens movements of said rotor.

2. An apparatus as claimed in claim 1 wherein said first winding of said motor means is wound over a stator having a plurality of slots with each winding being wound about one of said slots.

3. An apparatus as claimed in claim 1 wherein said windings comprise at least first and second phase windings, which are separately wound and separately energized to generate two radial forces.

4. An apparatus as claimed in claim 3 wherein said motor includes a stator having a plurality of slots said winding being wound over two of said slots.

5. An apparatus as claimed in claim 3 including circuit means for separately energizing each of said phases in order to modify the magnitude and direction of said radial force.

6. An apparatus as claimed in claim 5 including first and second probes associated with said rotor to measure a gyroscopic motion of said rotor or said shaft, output of said probes being processed to establish a signal applied to energize said first and second phase windings and stabilize said system.

7. An apparatus as claimed in claim 6 including means for adjusting the direction of said correction force relative to a reference direction corresponding to the position of said probes.

8. An apparatus as claimed in claim 7 including means for modifying the magnitude of said current applied to said first and second phases to adjust the magnitude of the correction force applied to said rotor.

9. An apparatus as claimed in claim 6 including a comb filter responsive to the output of said probe to separate components that are synchronous with the speed of said motor of said rotating system from components

that are not synchronous with said motor speed and represent oscillatory movements of said rotor to be dampened.

10. Apparatus as claimed in claim 1 wherein said actuator current and said drive current are separately applied in time to said windings.

11. Apparatus as claimed in claim 1 wherein said actuator current and said drive current are simultaneously applied to said windings.

12. An apparatus as claimed in claim 11 wherein said motor is selected from one of the configurations comprising 4 poles, 12 slots and 8 poles, 12 slots.

13. An apparatus as claimed in claim 6 wherein the phase number of the torque generating winding is a 2 phase, 3 phase or 5 phase motor.

14. An apparatus as claimed in claim 13 wherein said motor is an 8 pole, 20 slot configuration.

15. An apparatus as claimed in claim 6 wherein said motor is a 2 phase motor having a 2 pole, 8 slot configuration.

16. An apparatus as claimed in claim 6 wherein said motor is a 3 phase motor, and said actuator winding is a 3 phase winding generating 3 radial forces with directions separated by 120°.

17. An apparatus as claimed in claim 16 wherein said motor configuration is a 4 pole 6 slot, 8 pole 18 slot design.

18. An apparatus as claimed in claim 6 wherein said motor is a 5 phase motor, and said actuator is a 3 phase winding generating 3 radial forces with directions separated by 120°.

19. An apparatus as claimed in claim 18 wherein said motor is an 8 pole 30 slot motor.

20. An apparatus as claimed in claim 6 wherein said motor is a 2 phase motor, and said actuator comprises a 3 phase winding generating 3 radial forces with directions separated by 120°.

21. An apparatus as claimed in claim 20 wherein said motor is a 6 pole 12 slot, or 6 pole 24 slot motor.

22. An apparatus as claimed in claim 6 wherein said motor has a slotless winding, and said windings of said actuator are concentric but placed in the same airgap between a core and the rotating magnets of said motor.

23. An apparatus as claimed in claim 6 wherein the magnitude of the actuator is a function of the current flowing in the two phases of the actuator

where the relationship between the forces and the currents are defined as follows:

$$F_x = k_f \cdot i_{ph1} \cdot \cos(p \cdot \alpha) + k_f \cdot i_{ph2} \cdot \sin(p \cdot \alpha)$$

$$F_y = k_f \cdot i_{ph1} \cdot \sin(p \cdot \alpha) - k_f \cdot i_{ph2} \cdot \cos(p \cdot \alpha)$$

24. An apparatus as claimed in claim 6 wherein said actuator is a 3 phase actuator, and the relationship between the forces and the currents may be expressed as follows:

$$F_{pha} = \frac{2}{3} \cdot F_{ph1} \qquad \Rightarrow i_{pha} = \frac{2}{3} \cdot i_{ph1}$$

$$F_{phb} = \frac{1}{\sqrt{3}} \cdot F_{ph2} - \frac{1}{3} \cdot F_{ph1} \qquad \Rightarrow i_{phb} = \frac{1}{\sqrt{3}} \cdot i_{ph2} - \frac{1}{3} \cdot i_{ph1}$$

$$F_{phc} = -\frac{1}{\sqrt{3}} \cdot F_{ph2} - \frac{1}{3} \cdot F_{ph1} \qquad \Rightarrow i_{phc} = -\frac{1}{\sqrt{3}} \cdot i_{ph2} - \frac{1}{3} \cdot i_{ph1}$$

25. An apparatus for generating actuator currents for the apparatus of claim 6, including:

means for generating current signals as a function of rotor position;

means for multiplying said motor function currents by the respective detected forces, and means for summing said generated signals.

26. An apparatus as claimed in claim 1 further comprising:

means for sensing movements of said rotor;

comb means for separating non repeating movements from repeating movements of said rotor;

said actuator being responsive to said comb means to stabilize said rotor.

27. An apparatus as claimed in claim 26 wherein said actuator comprises first and second phase windings, which are separately wound and separately energized to generate two radial forces in quadrature.

28. An apparatus as claimed in claim 27 wherein the current to said phase windings is defined as:

$iph_i =$ a59

and $iph_2 =$ a60

where k_f is a function of coil opening s.

29. An apparatus as claimed in claim 28 wherein said actuator comprises said first, said second and a third phase windings, said windings being engaged by events as follows:

30. An apparatus as claimed in claim 28 comprising means for generating a signal defining each of said currents having first and second input signals representing components of said radial force to be generated, and a third input representing motor position;

memory means addressed with an argument of a function based on said rotor position for providing a trigonometric function based output based on said position; and

multiplier means responsive to said trigonometric function based output signal and said first and second input signals representing components of said radial force to generate elements of a said signal defining said currents.

31. An apparatus as claimed in claim 30 wherein said multiplier means comprises a digital/analog converter having said trigonometric based output signals as one input and one of said first and second signals representing said radial force as another input.

32. An apparatus as claimed in claim 31 including means for regularly resetting said signal generating means responsive to a motor driven pulse so that reset is proportional to motor rotational speed.

33. An apparatus as claimed in claim 32 including a circuit for incorporating an adjustable phase delay into said means for generating a current defining signal.

34. An apparatus for stabilizing the spin axis of a rotating system, said rotating system comprising:

a rotor carrying and inertial load and bearing means to support said rotor about said spin axis, and

motor means to cause rotation of said rotor about said spin axis comprising:

a first set of windings;

a source of drive current for causing relative rotation between said windings and said magnet; and

an actuator combined with a motor and comprising a source of actuator current energizing said windings to generate a radial force which stabilizes the position of said spin axis and dampens movements of said rotor.

35. An apparatus as claimed in claim 34 wherein said first winding of said motor means is wound over a stator having a plurality of slots with each winding being wound about one of said slots.

36. An apparatus as claimed in claim 34 wherein said windings comprise at least first and second phase windings, which are separately wound and separately energized to generate two radial forces.

37. An apparatus as claimed in claim 36 wherein said motor includes a stator having a plurality of slots said winding being wound over two of said slots.

38. An apparatus as claimed in claim 36 including circuit means for separately energizing each of said phases in order to modify the magnitude and direction of said radial force.

39. An apparatus as claimed in claim 38 including first and second probes associated with said rotor to measure a gyroscopic motion of said rotor or said shaft, output of said probes being processed to establish a signal applied to energize said first and second phase windings and stabilize said system.

40. An apparatus as claimed in claim 39 including means for adjusting the direction of said correction force relative to a reference direction corresponding to the position of said probes.

41. An apparatus as claimed in claim 40 including means for modifying the magnitude of said current applied to said first and second phases to adjust the magnitude of the correction force applied to said rotor.

42. An apparatus as claimed in claim 39 including a comb filter responsive to the output of said probe to separate components that are synchronous with the speed of said motor of said rotating system from components that are not synchronous with said motor speed and represent oscillatory movements of said rotor to be dampened.

43. Apparatus as claimed in claim 42 wherein said actuator current and said drive current are separately applied in time to said windings.

44. Apparatus as claimed in claim 39 wherein said actuator current and said drive current are simultaneously applied to said windings.

45. An apparatus as claimed in claim 44 wherein said motor is selected from one of the configurations comprising 4 poles, 12 slots and 8 poles, 12 slots.

46. An apparatus as claimed in claim 39 wherein the phase number of the torque generating winding is a 2 phase, 3 phase or 5 phase motor.

47. An apparatus as claimed in claim 46 wherein said motor is an 8 pole, 20 slot configuration.

48. An apparatus as claimed in claim 39 wherein said motor is a 2 phase motor having a 2 pole, 8 slot configuration.

49. An apparatus as claimed in claim 39 wherein said motor is a 3 phase motor, and said actuator winding is a 3 phase winding generating 3 radial forces with directions separated by 120°.

50. An apparatus as claimed in claim 49 wherein said motor configuration is a 4 pole 6 slot, 8 pole 18 slot design.

51. An apparatus as claimed in claim 39 wherein said motor is a 5 phase motor, and said actuator is a 3 phase winding generating 3 radial forces with directions separated by 120°.

52. An apparatus as claimed in claim 51 wherein said motor is an 8 pole 30 slot motor.

53. An apparatus as claimed in claim 39 wherein said motor is a 2 phase motor, and said actuator comprises a 3 phase winding generating 3 radial forces with directions separated by 120°.

54. An apparatus as claimed in claim 53 wherein said motor is a 6 pole 12 slot, or 6 pole 24 slot motor.

55. An apparatus as claimed in claim 39 wherein said motor has a slotless winding, and said windings of said actuator are concentric but placed in the same airgap between a core and the rotating magnets of said motor.

56. An apparatus as claimed in claim 39 wherein the magnitude of the actuator is a function of the current flowing in the two phases of the actuator where the relationship between the forces and the currents are defined as follows:

$$F_x = k_f \cdot i_{ph1} \cdot \cos(p \cdot \alpha) + k_f \cdot i_{ph2} \cdot \sin(p \cdot \alpha)$$

$$F_y = k_f \cdot i_{ph1} \cdot \sin(p \cdot \alpha) - k_f \cdot i_{ph2} \cdot \cos(p \cdot \alpha)$$

57. An apparatus as claimed in claim 39 wherein said actuator is a 3 phase actuator, and the relationship between the forces and the currents may be expressed as follows:

$$F_{pha} = \frac{2}{3} \cdot F_{ph1} \qquad \Rightarrow i_{pha} = \frac{2}{3} \cdot i_{ph1}$$

$$F_{phb} = \frac{1}{\sqrt{3}} \cdot F_{ph2} - \frac{1}{3} \cdot F_{ph1} \qquad \Rightarrow i_{phb} = \frac{1}{\sqrt{3}} \cdot i_{ph2} - \frac{1}{3} \cdot i_{ph1}$$

$$F_{phc} = -\frac{1}{\sqrt{3}} \cdot F_{ph2} - \frac{1}{3} \cdot F_{ph1} \qquad \Rightarrow i_{phc} = -\frac{1}{\sqrt{3}} \cdot i_{ph2} - \frac{1}{3} \cdot i_{ph1}$$

58. An apparatus for generating actuator currents for the apparatus of claim 39, including:

means for generating current signals as a function of rotor position;

means for multiplying said motor function currents by the respective detected forces, and means for summing said generated signals.

59. An apparatus as claimed in claim 34 further comprising:

means for sensing movements of said rotor;

comb means for separating non repeating movements from repeating movements of said rotor;

said actuator being responsive to said comb means to stabilize said rotor.

60. An apparatus as claimed in claim 59 wherein said actuator comprises first and second phase windings, which are separately wound and separately energized to generate two radial forces in quadrature.

61. An apparatus as claimed in claim 60 wherein the current to said phase windings is defined as:

$iph_i =$ a59

and iph_2 = a60

where k_f is a function of coil opening s.

62. An apparatus as claimed in claim 61 wherein said actuator comprises said first, said second and a third phase windings, said windings being engaged by events as follows:

63. An apparatus as claimed in claim 61 comprising means for generating a signal defining each of said currents having first and second input signals representing components of said radial force to be generated, and a third input representing motor position;

memory means addressed with an argument of a function based on said rotor position for providing a trigonometric function based output based on said position; and

multiplier means responsive to said trigonometric function based output signal and said first and second input signals representing components of said radial force to generate elements of a said signal defining said currents.

64. An apparatus as claimed in claim 63 wherein said multiplier means comprises a digital/analog converter having said trigonometric based output signals as one input and one of said first and second signals representing said radial force as another input.

65. An apparatus as claimed in claim 64 including means for regularly resetting said signal generating means responsive to a motor driven pulse so that reset is proportional to motor rotational speed.

66. An apparatus as claimed in claim 65 including a circuit for incorporating an adjustable phase delay into said means for generating a current defining signal.

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